

For the past 50 years, NASA and its partners have made steady progress in reducing hazardous aircraft emissions. But environmental restrictions have grown stricter just when requirements for lower costs and improved fuel efficiency have also increased. Balancing these needs will take precision and persistence, but current research projects hold promise for meeting the challenge.

Long gone are the days when weekend airplane watchers could visit an airport and see a Boeing 707 take to the skies, its four Pratt & Whitney JT3C jet engines belching soot and smoke out the rear as the airliner roared down the runway. Propulsion technology advances introduced by NASA working with many others during the past 50 years have markedly reduced harmful engine emissions. But more still needs to be done.

NASA is collaborating with its government, industry, and university partners on a number of environmentally beneficial, or 'green,' aviation initiatives designed to eliminate as much potential harm to the ecosystem as possible while still making air travel as efficient and economical as it can be. Emissions, nuisance noise, fuel burn efficiency, air traffic management, and the use of alternate fuels all are on NASA's 'home improvement' radar.

Clearing the air

Depending on their chemical composition, the potentially harmful jet engine emissions of greatest concern to NASA researchers affect either the global atmosphere or the air quality in airport neighborhoods.

PART TWO

In search of

Landing and takeoff emissions—found on and around airport property—include nitric oxide and nitrogen oxide (collectively called NO_x), plus sulfur oxides and particulates, also known as soot, smoke, or aerosols. Both NO_x and particulate emissions create hazards for humans. In the lower atmosphere, smog is the primary concern. NO_x also contributes to atmospheric ozone depletion, which increases potential exposure to ultraviolet solar radiation, a situation linked to skin cancer. Particulates contribute to respiratory problems. Sulfur oxides can mix with airborne moisture and fall as acid rain, which can erode vehicle paint finishes, irritate exposed skin, and damage crops.

At altitude, carbon dioxide and water vapor contrails are the chief concerns. CO_2 traps excess heat from the Sun, exacerbating the greenhouse effect in the atmosphere. Water vapor from engine exhaust also traps solar radiation, but scientists have not yet determined whether that contributes significantly to the greenhouse effect.

Using data from NASA's atmospheric research satellites, Patrick Minnis, a senior research scientist in the Science Directorate at NASA Langley, has found that contrails

formed as a result of jet engine water vapor emissions often spread out to become high-altitude cirrus clouds. "We are finding that in areas where there is air traffic, either locally over airports or on the nation's jet ways, there is an increased frequency of cirrus clouds," Minnis says. "What we don't know yet is the extent to which these cirrus clouds are having an effect on the total amount of radiative energy that is trapped in the atmosphere."

"The impact of these contrails may be no worse than what we see with [CO_2], or it may be many times worse. We just don't know enough yet," says Minnis.

NASA's aeronautics innovators are turning to the science community to develop a better understanding of the atmospheric impacts of aircraft emissions, because that will directly affect the technical direction of future aircraft and engine design changes intended to help the environment.

"Because of the uncertainty about the true impact of emissions on the global environment, future aircraft engines designed to eliminate one type of emission, such as NO_x , could create a bigger problem with something like contrails or water vapor," says Jay Dryer, director of NASA's Funda-

by Jim Banke
Public Affairs writer,
NASA Headquarters;
President, MILA Solutions,
a NASA subcontractor



cleaner skies

mental Aeronautics Program in Washington, D.C. “We just don’t know enough yet about what is really happening, so there’s a lot of discovery still to come.”

Setting new standards

For now, based on what is known and already established in terms of national and international standards (landing and takeoff NO_x is regulated while carbon dioxide is not), NASA has set several goals for enabling technology that will reduce emissions during the next decade or so. These goals are based on standards set forth by the Committee on Aviation Environmental Protection, or CAEP, which is part of the International Civil Aviation Organization.

The CAEP meets every three years. During the 2004 meeting, members set new emissions standards for aircraft engines. These standards—labeled CAEP/6 because the 2004 meeting was the sixth in the organization’s history—took effect in 2008. NASA’s goals, related to the current standard, are to create technology enabling engines that emit 60% less NO_x by 2015, 75% less by 2020, and over 75% less by 2025.

Although there are no carbon dioxide emissions standards or restrictions, the 2010 CAEP/8 committee members expressed a desire to develop a new CO_2 standard by 2013, when they meet again. If they reach an agreement at CAEP/9, new CO_2 standards would apply to all new aircraft engines in the 2016-2017 timeframe.

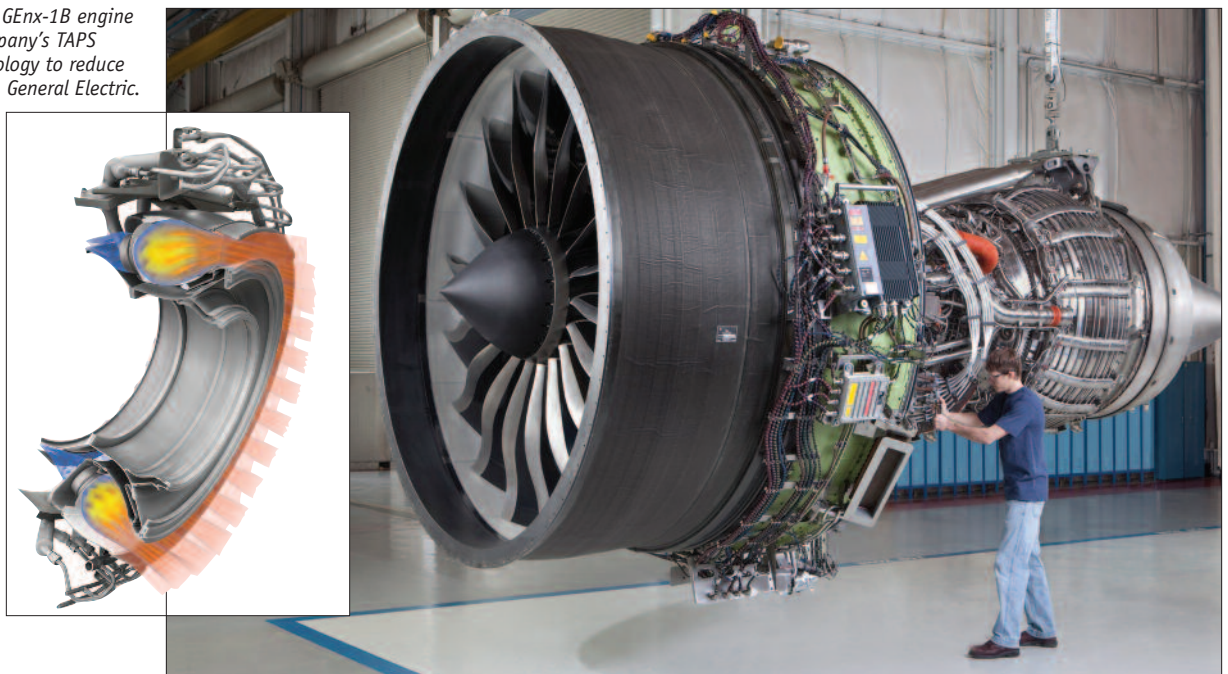
The continuing challenge for NASA researchers is to design aircraft and engines that not only meet stringent new goals for emissions, but also will satisfy simultaneous goals for noise reduction and fuel burn efficiency—no matter what type of fuel, alternative or otherwise, is in vogue 20-25 years from now.

Burn, baby, burn

The amounts of chemicals and particulates spewing from a jet engine exhaust nozzle have everything to do with the combustion process involving fuel and air. Change any one of the many variables that affect combustion and the resulting emissions get better or worse. An engine’s internal geometry, its operating pressure and temperature, the fuel injection method, the ratio of fuel to air and how well they are mixed together inside the combustor before ignition are just a few of the top-level variables. The type of aviation fuel used, whether fossil fuel based or not, also can affect the amounts and types of emissions.

Right now, NASA researchers and their industry colleagues are focused on reducing the amounts of landing and takeoff NO_x and particulate emissions, which are the direct result of burning standard aviation fuel inside today’s combustors. To that end, NASA has three teams—two from industry and one from government—looking at new ideas for reducing engine emissions. “The new concepts resulting from this

General Electric’s GEnx-1B engine includes the company’s TAPS combustor technology to reduce emissions. Credit: General Electric.



teaming will be tried out in a partial engine test in a ground test facility, as well as a full engine test on the ground or in flight, in order to conduct research at an integrated system level and demonstrate the benefits in a relevant environment,” says Fay Collier, manager of NASA’s Environmentally Responsible Aviation Project at Langley.

Ruben Del Rosario, project manager of the Subsonic Fixed Wing Project at NASA Glenn, says the agency and its industry partners “have some concepts that show potential for meeting our goals for reducing emissions,” but notes that “we’re very early in the process” of developing cleaner burning engine technology. “Now, as we continue to develop our concepts, we may find some of the ideas won’t work as well as the others,” Del Rosario says.

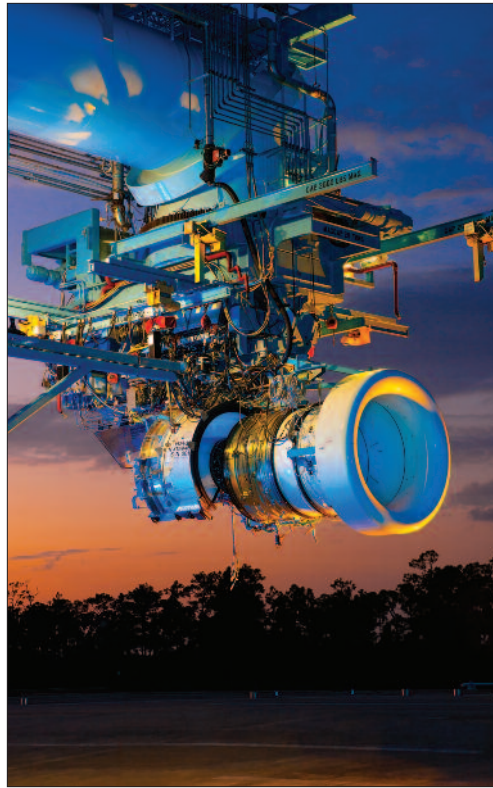
Of the three concepts now under development, General Electric is leading the first, Pratt & Whitney the second, and NASA the third, in-house. In each case, the designs are not necessarily brand new, but could best be described as evolutionary versions of concepts already flying. And in each case, engineers are concentrating on the mechanics and the resulting fluid dynamics of mixing the fuel and air more efficiently before it is ignited in the combustor—albeit with slightly different design philosophies.

“Our job is very difficult, because we have to reduce emissions regardless of how much pressure you operate at. So the key for NO_x reduction is to improve the fuel injector design to create a homogeneous mixing of fuel and air,” says Chi-Ming Lee, head of the Combustion Branch at NASA Glenn.

A swirl of ideas

This NASA/GE technology program will further advance the industry’s knowledge of ultra-high-pressure ratio engines, which GE considers to be the future of gas turbine engines in aviation. One area where the company has made great strides is in the engine combustor. GE has developed a concept called the twin annular premixing swirler, or TAPS. The company has been working on the concept for almost a decade and has recently introduced the technology on its GEnx engine, which powers Boeing’s new 787 and 747-8, marking the first time TAPS is being used on a commercial product.

TAPS takes air from the engine’s high-pressure compressor and directs it into a pair of ring-shaped, high-energy swirlers lo-

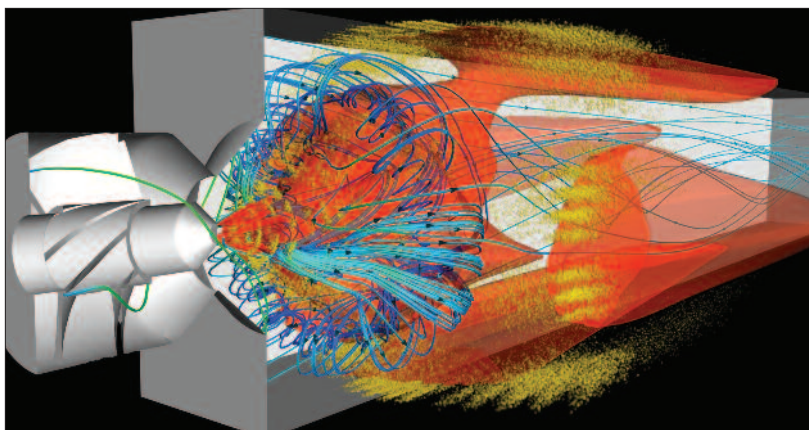


Pratt & Whitney’s PurePower 1000G engine uses the TALON X combustor.

cated next to the fuel nozzles. The swirlers, configured concentrically, create turbulence in the air flowing through the engine to help the air mix better with the fuel. The inner swirler operates when the airplane is idling or taxiing. The outer swirler operates at higher throttle settings. Combustion is staged. Fuel and air mix together at the front of the combustor and ignite. As hot gases move through the combustor, more air is added and the resulting mixture ignites again. This process distributes combustion to alleviate the hot spots responsible for unwanted emissions.

Tests have shown that swirling creates a more homogeneous and leaner mix of fuel and air, which then burns at a lower temperature and promotes fewer emissions without sacrificing overall engine stability. Operating the TAPS combustor at a lower temperature than would be the case with a fuel-rich mixture minimizes wear and tear on the combustor liner and other engine components further downstream.

Pratt & Whitney’s approach calls for improvements to its long-established technology for advanced low NO_x , or TALON X, combustor. This design relies heavily on its ability to maintain a certain temperature profile that allows the emission reduction goals to be achieved. In this case, the initial mix of fuel and air in the combustor is fuel



In the LDI process, air flows through the swirler (shown as streamtubes, colored by velocity magnitude), producing a toroidal recirculation zone. Fuel is injected at the center of the venturi. The hot combustion zone (red isosurface) is shaped by the recirculation zone, which is critical to combustion stability, but also produces NO_x . Anthony C. Iannetti, NASA Glenn.

rich. Combustion gases combine rapidly with more air in what Pratt & Whitney calls an 'advanced quick quench zone,' which cools the hot gas and makes the mixture leaner. This is possible because of the combustor's ability to direct the flow of air and manage the overall heat load. As with the TAPS combustor, the TALON X minimizes operating temperatures, NO_x emissions, and engine wear and tear.

NASA's in-house concept is called lean direct injection. As the name implies, this combustor design is meant to operate with a fuel/air mixture that is leaner, thus lowering the operating temperature and making it more difficult for NO_x to form during the combustion process. In this case, a jet of liquid fuel is injected at high speed into a rapidly swirling airflow that promotes the mixing of fuel and air across the shortest possible distance. For this concept to work, the fuel and air must be mixed perfectly before combustion takes place.

Additional research contract awards are expected soon to further these combustor concepts and deliver hardware to NASA, says Dan Bulzan, the agency's technical lead for the clean energy and emissions subproject at Glenn. "The hardware is going to be different from what's out there, but the specific configurations and designs for the injectors, the pilots, the swirlers—all of that is considered proprietary right now."

NASA is working to get this technology mature enough for entry into service by 2025, but when it actually might see use in a commercial setting is not clear, according to Lee. Much will depend on what new regulations or standards are set on NO_x and carbon dioxide emissions in the near future, and on whether or not additional research on the hardware will be necessary to meet those goals.

"That's a very complex environment when you're talking about combustors. We are spraying fuel, mixing it with air. We need to understand how fuel flows and mixes, and be able to model it well so we can design newer, more efficient systems, and at the same time invent and test new materials. There's just a variety of ways we can work to reduce emissions in our engines," Dryer says.

Changing the fuel

Another way to change what is coming out of the engines is to find something different to put into the engine in terms of fuel. Using some types of alternative fuels could instantly eliminate whole categories of harmful emissions. Yet the cost to develop those fuels, in terms of price and their impact to other areas of the environment, makes it unclear what their ultimate value will be to the aviation industry.

"I think they are promising, but we are a long way from having these alternate fuels available at the airport pumps," says Bruce Anderson, project scientist for the Alternative Aviation Fuel Experiment (AAFEX) at Langley. Through AAFEX, NASA has been working with the FAA, the U.S. military, industry, and universities to help characterize the potential value and effects of alternative sources of fuel on the environment and on aircraft systems.

The most comprehensive examination to date of alternate fuels was performed at NASA Dryden's Aircraft Operations Facility in Palmdale, California, in 2009. The experiment, known as AAFEX 1, used Fischer-Tropsch fuel, which is aviation fuel derived from coal and natural gas instead of the usual oil. Researchers used a DC-8 aircraft with four workhorse GE CFM-56 engines in a ground test. They equipped two of the four engines with sensors and put them through their paces with alternative fuel, running the engines at power levels representing idle, taxi, takeoff, climb out, approach, and landing.

The team showed that the fuel burned well and that particulates and NO_x were greatly reduced when pure Fischer-Tropsch fuel or blends of Fischer-Tropsch and standard JP-8 fuel were burned. Carbon dioxide emissions remained unchanged, and researchers noted problems with engine seals leaking when the aircraft fuel tanks were filled with pure Fischer-Tropsch fuel and not the JP-8 blend.

In March, researchers planned to con-



A maze of wires and tubing that connects data-collection instrumentation to the control centers is laid out on the pavement beside the DC-8 flying laboratory during synthetic fuels emission and performance testing.

duct a second round of ground tests, repeating many of the AAFEX 1 measurements of gas emissions and particle size, number, distribution, and composition with the same aircraft engines but with different fuel. This time, they planned to use a bio-fuel derived from the oil of algae or another natural source.

Competing demands

Complicating the picture for green aviation engine designers is the need to balance all the demands of increased fuel burn efficiency, reduced emissions, and quieter aircraft and engines—all with the promise and challenges of a new alternative fuel dangling in front of them.

It is easy to reduce NO_x emissions by lowering the temperature and the pressure within the combustor, but doing so decreases fuel efficiency. The reverse is true as well: Fuel burns more efficiently at higher temperatures, but more soot and carbon dioxide escape into the atmosphere.

“With the increasingly realistic expectation that alternative fuels will be adopted and served up at every airport, you can’t expect to pick just one blend and stick with it,” explains Rich Wahls, project scientist for

the Subsonic Fixed Wing Project at Langley. “The landscape of the future of fuels is wide open right now, and when someone buys an engine, they’re going to use it for decades; so they’re going to need to be able to use it with whatever fuels get developed in the future,” he continues. “Fuel flexibility is key.”

Achieving cleaner engines and cleaner skies rests on smart navigation through the landscape of possible solutions in the near term. What is clear for now is that propulsion technology is on the path to change. **A**

Editor’s note: This is the second of four features describing the challenges associated with trying to invent a truly ‘green’ airplane. The first feature (March 2011) covered research into reducing nuisance noise around airports. Future articles will cover work on technology to boost fuel efficiency and enable the nation’s air traffic management system to handle aircraft in a more environmentally responsible manner.



Test instrumentation is set up behind the inboard engines of NASA’s DC-8 airborne science laboratory during alternative fuels emissions and performance testing. Image credit: NASA Dryden/Tom Tschida.